National Aeronautics and Space Administration

Glory

SCIENCE WRITERS' GUIDE

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Revealing the Effects of Aerosols and Solar Irradiance on Climate

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TABLE OF CONTENTS

Science Overview 4

Instruments 5

Feature Stories

New Sun-Watching Instrument to Monitor Sunlight Fluctuations 6

Glory Promises a New View of Perplexing Airborne Particles 8

With A-List Help, Glory Aims to Unravel Uncertainties About Aerosols 10

The Glory Mission's Judith Lean Discusses Solar Variability 12

Glory Spokespersons 14

Glory Science Team 15

SCIENCE OVERVIEW

Credit: NASA

Glory, NASA's newest Earth-observing satellite, will improve measurements of two critical parts of the climate system: small airborne particles called aerosols and a measure of the sun's output called total solar irradiance (TSI). Refining measurements of both will make it possible to calculate the energy budget—the measure of incoming radiation from the sun and outgoing radiation reflected and emitted by Earth—more accurately.

Understanding the energy budget is essential for understanding climate change. Ramp up the amount of energy trapped in the atmosphere too much, and rising temperatures could evaporate the oceans and leave a scorching Earth reminiscent of Venus. Dial it back a notch and Earth could become a freezing world like Mars.

Earth is a long way from either of these extremes, but the climate is slowly changing. During the last century, global average temperatures at the surface have increased 0.7°C (1.3°F). And climate models estimate that temperatures will increase by another 1.1°C to 6.4°C (2.0°F to 11.5°F) during the twenty-first century.

Such amounts may seem small, yet even increases on this scale could have profound consequences for humans. Rising sea levels, changing ocean currents, and fiercer storms, coupled with altered cloudiness, rainfall patterns, and changing growing seasons are real possibilities confronting our home planet.

In the last few decades, climatologists have gone to great lengths to understand and quantify what happens to the solar radiation that reaches Earth's atmosphere. The best estimates to date suggest that each square meter of the atmosphere receives an average of 341 watts of radiation from the sun, less than half of what reaches the top of Venus' atmosphere, and about twice as much as Mars receives.

However, not all of that radiation affects Earth's climate directly. About 23 percent reflects off clouds and aerosols and goes back into space. Another 7 percent gets reflected by the surface. The rest is absorbed by atmospheric gases, aerosols, or Earth's surface and can affect the climate. But the climate system is stunningly complex, and scientists are still in the process of refining calculations of the energy budget.

Much of the uncertainty that remains about the energy budget relates to aerosols. Aerosol particles, which can be either natural or human-generated, can cool or warm Earth by scattering or absorbing light and changing the properties of clouds. Scientists know the particles can have a strong impact on climate, but they have not yet determined the precise magnitude of that impact.

Of the 25 climate models considered by the Intergovernmental Panel on Climate Change (IPCC) for the group's last major report, only a handful considered the climate impacts of aerosols other than a well-studied type of aerosol particle called sulfates. And less than a third included aerosol impacts on clouds, even in a limited way.

Aerosols are not the only aspect of the climate system that requires additional study. Variations in the sun can also have an impact. Overall, scientists believe the sun has brightened slightly in the last 100 years, causing a very small degree of warming. And though solar variations are too small to account for the warming seen on Earth since the beginning of the industrial era, many questions about the sun's long-term variability remain.

There are hints that solar cycles longer than the well-known 11-year cycle might affect Earth's climate, but climatologists need a long-term record of the sun's irradiance to explore this possibility. An instrument on board Glory will help provide more definitive answers by continuing and improving a 30-plus year record of total solar irradiance.

Orbital Sciences Corporation operates the Glory spacecraft from Dulles, Virginia. The Laboratory for Atmospheric and Space Physics (LASP) in Boulder, Colorado commands the solar irradiance-observing instrument. The Goddard Institute for Space Studies (GISS) in New York City manages the aerosol-monitoring instrument. All data products will be archived and distributed by the Goddard Earth Sciences Data and Information Services Center (GES DISC) at NASA's Goddard Space Flight Center (GSFC) in Greenbelt, Maryland.

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INSTRUMENTS

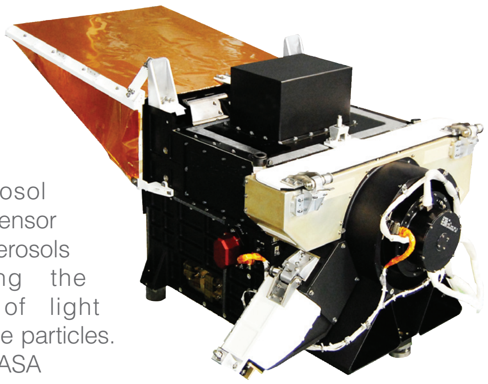
Two instruments aboard Glory—the Aerosol Polarimetery Sensor (APS) and the Total Irradiance Monitor (TIM)—supply information about critical components of Earth's climate system. The APS, a polarimeter mounted on the underside of the Glory spacecraft and facing downward, collects information about aerosol properties. The TIM, which is located on the opposite side of the spacecraft and faces toward the sun, measures the intensity of incoming solar radiation at the top of the atmosphere.

AEROSOL POLARIMETRY SENSOR

The design of the APS stretches back to the 1970s, when James Hansen, now director of NASA's Goddard Institute for Space Studies, conducted studies on the polarization of light from Venus. By studying polarization—a measure of the physical orientation of light waves as they move and twist through space—Hansen managed to deduce the composition of the clouds in Venus' atmosphere.

The success of such efforts led engineers to develop similar instruments for use on Earth. In 1999, NASA developed an aircraft-based polarimeter, called the Research Scanning Polarimeter (RSP), for example, that has demonstrated the power of this technique for providing detail about Earth's aerosols. The Glory APS, which has a nearly identical design to the RSP, will be NASA's first instrument capable of applying this method to study aerosols globally from space.

The APS, built by Raytheon Space and Airborne Systems in El Segundo, Calif., measures aerosols from more than 250 angles using nine different spectral channels. The 69-kilogram (152-pound) instrument views Earth's surface in 5.9-kilometer (3.7-mile) bands along the sub-satellite track that repeats every 16 days. Unpolarized light that enters the APS strikes a mirror, passes through a series of lenses that collect and focus the beams, and then gets split by a prism into polarized planes that nearby detectors can measure.



Glory's Aerosol Polarimetry Sensor (APS) tracks aerosols by measuring the polarization of light scattered by the particles. Photo credit: NASA

Glory carries secondary instruments called cloud cameras that will support APS by tracking clouds as they pass through APS' sights. These cameras will help scientists remove cloud-contaminated scenes that can hamper analysis of the data.

TOTAL IRRADIANCE MONITOR

Glory's TIM instrument, a type of radiometer, has an important objective: maintain and improve a decades-long record of total solar irradiance. Though mistakenly considered constant, the amount of incoming solar radiation striking the top of Earth's atmosphere actually fluctuates slightly as the sun cycles through periods of more and less intense electromagnetic activity.

The TIM will collect high-accuracy, high-precision measurements of total solar irradiance using an active cavity radiometer that monitors changes in sunlight incident on Earth's atmosphere. Photo credit: LASP

TIM is an improvement of a similar instrument launched in 2003 as part of NASA's Solar Radiation and Climate Experiment (SORCE) mission. The Glory TIM, designed at LASP at the University of Colorado, should be at least three times more accurate than previous instruments.

In the past, subtle differences in the design and calibrations of TSI instruments have caused noticeable offsets in the data. In most cases, scientists have had to correct for such discrepancies by matching up data between overlapping missions. While still important, overlapping missions will become somewhat less crucial because the Glory TIM has been calibrated at an innovative ground-based facility at LASP called the TSI Radiometer Facility.

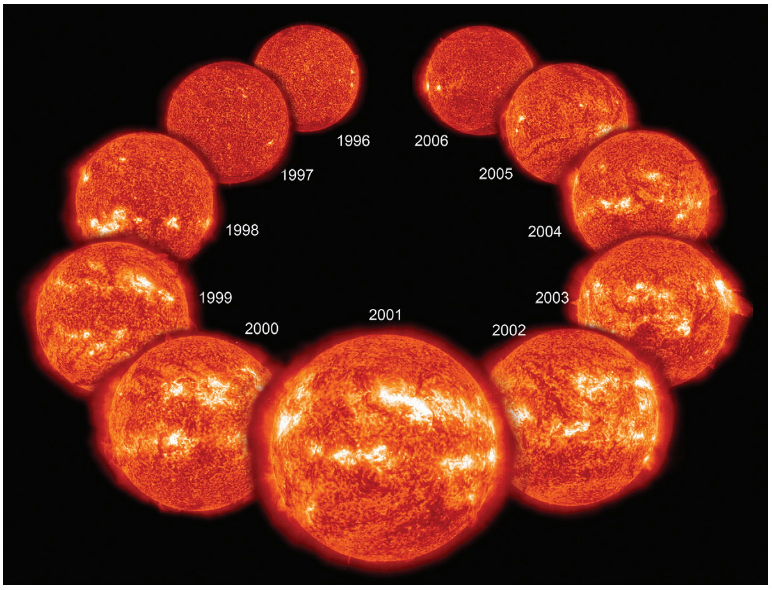
The TIM instrument contains four identical radiometers capable of monitoring the sun during the daylight portion of each orbit. It sits on a gimbaled platform that allows mission controllers to aim it toward the sun independently of the orientation of the spacecraft. Scientists at LASP will process the data TIM gathers, and post it on the web for use in climate and solar science within days of acquisition.

FEATURE STORIES

NEW SUN-WATCHING INSTRUMENT TO MONITOR SUNLIGHT FLUCTUATIONS

During the Maunder Minimum, a period of diminished solar activity between 1645 and 1715, sunspots were rare on the face of the sun, sometimes disappearing entirely for months to years. At the same time, Earth experienced a bitter cold period known as the "Little Ice Age."

Were the events connected? Scientists cannot say for sure, but it's quite likely. Slowdowns in solar activity—evidenced by reductions in sunspot numbers—are known to coincide with decreases in the amount of energy discharged by the sun. During the Little Ice Age, though, few would have thought to track total solar irradiance (TSI), the amount of solar energy striking Earth's upper atmosphere. In fact, the scientific instrument needed to make such measurements—a spaceborne radiometer—was still three centuries into the future.



During periods of peak activity (front three images) sunspots, solar flares, and coronal mass ejections are more common, and the sun emits slightly more energy than during periods of low activity (back images). The amount of energy that strikes Earth's atmosphere—called total solar irradiance (TSI)—fluctuates by about 0.1 percent over the course of the sun's 11-year cycle. Credit: Steele Hill, SOHO, NASA/ESA

Modern scientists have several tools for studying TSI. Since the 1970s, scientists have relied upon a collection of radiometers on American and European spacecraft to keep a close eye on solar fluctuations from above the atmosphere, which intercepts much of the sun's radiation. When NASA launches the Glory satellite this winter (no earlier than February 2011), researchers will have a more accurate instrument for measuring TSI than they have ever had before.

The Total Irradiance Monitor (TIM) on Glory is more sophisticated, but still related in concept to the very earliest ground-based solar radiometers, which were invented in 1838. Whereas those radiometers used sunlight to heat water and indicate the intensity of the sun's brightness at the Earth's surface, Glory's TIM instrument will use a black-coated metallic detector to measure how much heat is produced by solar radiation as it reaches the top of the Earth's atmosphere.

Solar bolometers, as this subset of radiometers is called, have been flown on ten previous missions. Nimbus-7, launched in 1978, included one of the first spaceborne bolometers, and progressively more advanced instruments have followed on other NASA, National Oceanic and Atmospheric Administration, and European Space Agency missions.

In 2003, a first-generation TIM instrument went aloft with the SORCE satellite. Learning from that instrument, engineers have tweaked the optical and electrical sensors to make the Glory TIM even more capable of measuring the true solar brightness and its fluctuations.

"The Glory TIM should be three times more accurate than SORCE TIM, and about ten times more accurate than earlier instruments," said Greg Kopp, a physicist at the University of Colorado, Boulder, and leader of the TIM science team.

"There's no doubt that's an ambitious goal, but I wouldn't be surprised if they pull it off," said Joseph Rice, a physicist at the National Institute of Standards and Technology in Gaithersburg, Maryland.

Beyond engineering improvements, the Glory irradiance monitor has another advantage: access to a one-of-a-kind TSI Radiometer Facility. Funded by NASA and built by the Laboratory for Atmospheric and Space Physics (LASP) in Boulder, Colorado, the new facility has allowed Kopp's team to calibrate the instrument in the same configuration and under the same conditions as it will endure in space. In January 2009, the Glory TIM instrument underwent a rigorous battery of tests while being compared to a highly accurate ground-based radiometer.

"This was the first time a TSI instrument has ever been validated end-to-end to these accuracies," Kopp said. "The improvements in accuracy will make it possible to detect long-term changes in the sun's output much more quickly." The

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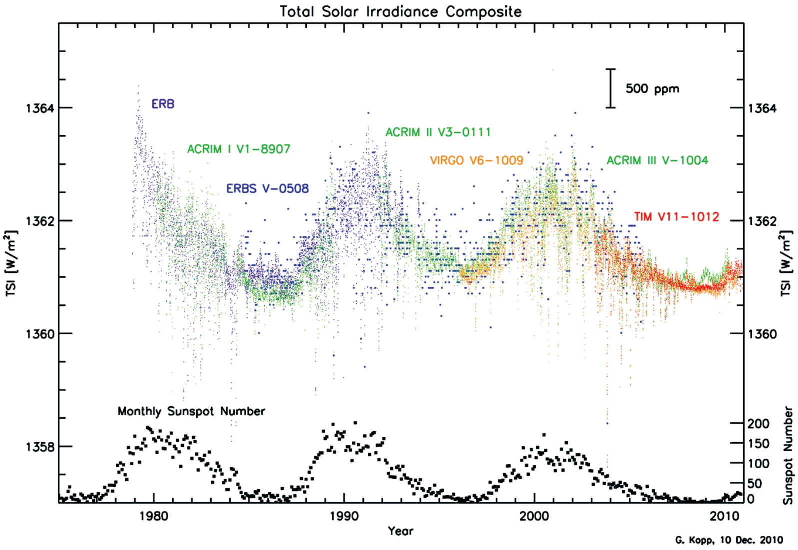
data will help scientists say more definitively whether the sun's output is gradually trending upward or downward, and whether the trend is influencing the pace of climate change.

Existing measurements offer a rough sketch, but they're not quite accurate enough over decades to centuries to paint a clear picture of whether changes in TSI reflect real changes on the sun or just artifacts of different instrument designs. That's because the radiometers that have measured TSI so far have all reported values at slightly different levels and have all been calibrated differently, injecting a degree of uncertainty into the record.

The new TIM should be sufficiently accurate to yield more definitive data on whether solar irradiance is trending up or down. Modelers estimate that TSI increased roughly 0.08 percent as the sun exited the Maunder Minimum, which lasted for much of the 1700s. But even if TSI radiometers had been available at the time, the increase in irradiance was so gradual that identifying the trend would have been difficult.



Scientists have compiled a three-decade record of total solar irradiance by patching together data from U.S. and European satellites. Fluctuations in irradiance correspond well with the cycling of sunspots. To ensure continuity, data from Glory's TIM instrument must overlap with data from an earlier TIM (in red on this plot), which launched in 2003. Credit: Greg Kopp, LASP

Detecting such subtle changes is where the Glory TIM will shine. Prior to SORCE, most TSI instruments had only 0.1 percent accuracy, and could not have reliably detected a 0.08 percent change over a century, Kopp explained. The improved accuracy of the SORCE TIM (0.035 percent) would detect such a change in about 35 years. The Glory TIM, meanwhile, should reduce the time needed to nearly ten years.

Getting TSI right has profound implications for understanding Earth's climate. Thanks to previous orbiting radiometers, scientists know TSI varies by roughly 0.1 percent through the sun's 11-year magnetic cycle. Such a variation cannot cause the intensity and speed of the warming trends on Earth during the last century, noted Judith Lean, a solar physicist at the U.S. Naval Research Laboratory in Washington, D.C. But, that's not to say that the sun has no influence on climate change.

While total solar irradiance changes by 0.1 percent, the change in the intensity of ultraviolet light varies by much larger amounts, scientists have discovered. Research shows such variations in the sun's emissions can affect the ozone layer and the way energy moves both vertically and horizontally through the atmosphere.

After examining the historical TSI database, some scientists have suggested that solar irradiance could account for as much as a quarter of recent global warming. But without a continuous and reliable TSI record, Kopp and Lean point out, there will always be room for skeptics to blame global warming entirely on the sun, even when most evidence suggests human activities are the key influence on modern climate changes.

Beyond that, there's a big "what if" percolating through the scientific community. The 0.1 percent variation in solar irradiance is certainly too subtle to explain all of the recent warming. "But, what if—as many assume—much longer solar cycles are also at work?" said Lean. In that case, it's not impossible that long-term patterns—proceeding over hundreds or thousands of years—could cause more severe swings in TSI.

Could a modern day Maunder Minimum offset the warming influence of greenhouse gases or even throw us back into another little ice age? "It's extremely unlikely," said Lean, "but we won't know for sure unless we keep up and perfect our measurements."

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Related Links:

NASA's Glory Mission Websites:
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FEATURE STORIES

GLORY PROMISES A NEW VIEW OF PERPLEXING AIRBORNE PARTICLES

Climatologists have known for decades that airborne particles called aerosols can have a powerful impact on the climate. However, pinpointing the magnitude of the effect has proven challenging because of difficulties associated with measuring the particles on a global scale. Now a new NASA satellite—Glory—should help scientists collect the data needed to provide firmer answers about the important ubiquitous particles.

Aerosols, or the gases that lead to their formation, can come from vehicle tailpipes and desert winds, from sea spray and fires, volcanic eruptions and factories. Even lush forests, soils, or communities of plankton in the ocean can be sources of certain types of aerosols.

The ubiquitous particles drift in Earth's atmosphere, from the stratosphere to the surface, and range in size from a few nanometers, less that the width of the smallest viruses, to several tens of micrometers, about the diameter of human hair.

The particles can directly influence climate by reflecting or absorbing the sun's radiation. In broad terms, this means bright-colored or translucent aerosols—such as sulfates and sea salt aerosols—tend to reflect radiation back towards space and cause cooling. In contrast, darker aerosols—such as black carbon and other types of carbonaceous particles—can absorb significant amounts of light and contribute to atmospheric warming.

Research to date suggests that the cooling from sulfates and other reflective aerosols overwhelms the warming effect of black carbon and other absorbing aerosols. Indeed, the best climate models available show that aerosol particles have had a cooling effect that has counteracted about half of the warming caused by the build-up of greenhouse gases since the 1880s.

"However, the models are far from perfect," said Glory Project Scientist Michael Mishchenko, a senior scientist at the Goddard Institute for Space Studies (GISS). "The range of uncertainty associated with the climate impact of aerosols is three or four times that of greenhouse gases," he said.

Indeed, in comparison to greenhouse gases, aerosols are short-lived, and dynamic—making the particles much harder to measure than long-lived and stable carbon dioxide. Aerosols usually remain suspended in the atmosphere for just a handful of days. Complicating matters, the particles can clump together to form hybrids that are difficult to distinguish.

In addition to scattering and absorbing light, aerosols can also modify clouds. They serve as the seeds of clouds, and can also affect cloud brightness and reflectivity, how long clouds last, and how much they precipitate. Infusions of reflective aerosols like sulfates, for example, tend to brighten clouds and make them last longer, whereas black carbon from soot seems to have the opposite effect.

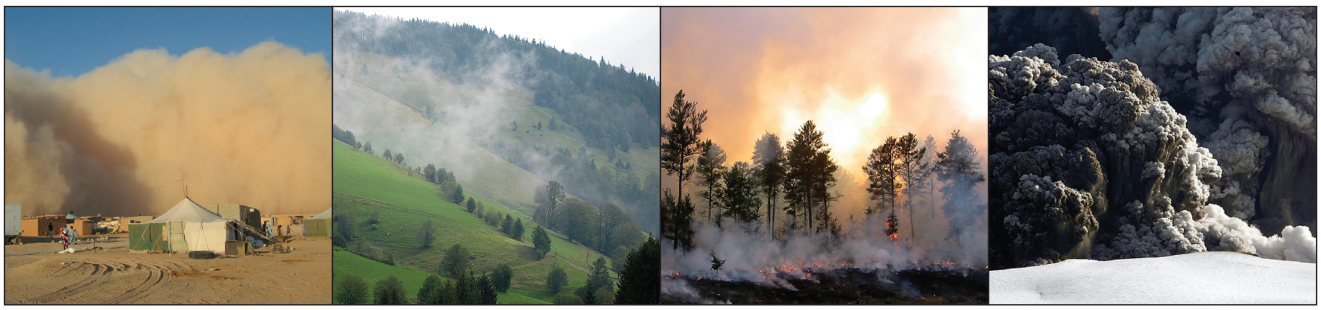
Still, much remains unknown about aerosols and clouds. How do aerosols other than sulfates and black carbon affect clouds? How do aerosol impacts differ in warm and cold environments? Can infusions of aerosols near clouds spark self-reinforcing feedback cycles capable of affecting the climate?

The climate impact of clouds remains one of the largest uncertainties in climate science because of such unanswered questions. Indeed, some models suggest a mere 5 percent increase in cloud reflectivity could compensate for the entire increase in greenhouse gases from the modern industrial era, while others produce quite different outcomes.

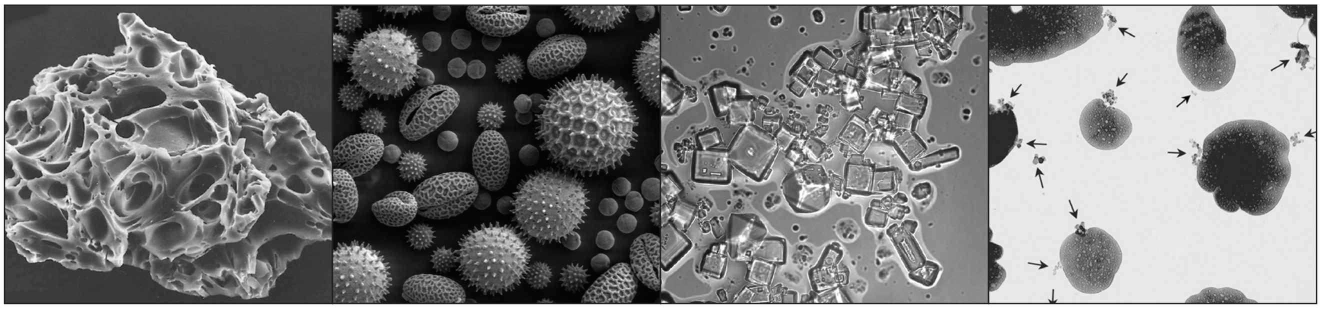
Such unresolved issues caused the Intergovernmental Panel on Climate Change (IPCC) to list the level of scientific understanding about aerosols as "low" in its last major report. Of the 25 climate models included by the IPCC in its Fourth Assessment Report, only a handful considered the scattering or absorbing effects of aerosol types other than sulfates.

"And less than a third of the models included aerosol impacts on clouds, even in a limited way, and those that did only considered sulfates," said Mian Chin, a physical scientist at NASA's Goddard Space Flight Center who specializes in modeling aerosols.

Glory, which contains an innovative aerosol-sensing instrument called the Aerosol Polarimetry Sensor (APS), aims to change



Desert dust, volatile organic compounds from vegetation, smoke from forest fires, and volcanic ash are natural sources of aerosols. Photographs copyright (left to right) Western Sahara Project, Lebewesen, Ross Orr, and Ludie Cochrane.



These scanning electron microscope images (not at the same scale) show the wide variety of aerosol shapes. From left to right: volcanic ash, pollen, sea salt, and soot. Micrographs courtesy USGS, UMBC (Chere Petty), and Arizona State University (Peter Buseck).

this. By more accurately identifying a broad suite of aerosol types—such as salt, mineral dust, and smoke—the instrument should help climatologists fill in key gaps in climate models.

While other NASA instruments—including ground, aircraft, and satellite-based instruments—have studied aerosols in the past, APS is NASA's first satellite-based instrument capable of measuring the polarization, the orientation of light wave vibrations.

Raw sunlight, explained Mishchenko, is unpolarized. This means the waves oscillate in an unpredictable, random fashion as they move through space, much like a rope would wiggle about if it had two people flapping its ends up and down in no particular pattern.

When light waves pass through certain types of filters called polarizers, they are forced into a more ordered form. Imagine that wobbling rope trying to pass throw a narrow slit in a fence: only the waves vibrating at a certain angle could make it through. The result is polarized light, or light for which the waves only oscillate at specific angles. The surface of glass, sunglasses, even plumes of aerosol particles, can polarize light.

APS's ability to measure the polarization of light scattered by aerosols and clouds is the key strength of the instrument. Other NASA satellite instruments have measured aerosols, but such instruments have typically done so by looking at the intensity of light—the amplitude of the light waves—not the polarization of the waves.

Ground and aircraft-based studies, particularly those conducted with an aircraft instrument called the Research Scanning Polarimeter (RSP), show that polarized light contains the most information about aerosol features. "Earlier instruments can approximate the abundance of aerosol in general terms, but they leave much to be desired if you're trying to sort out the shape and composition of the particles," said APS Instrument Scientist Brian Cairns, also of GISS.

Large, spherical particles—sea salt, for example—leave a very different imprint on light in comparison to smaller and more irregularly-shaped particles such as black carbon. As a result, much like forensic scientists might study the details of blood droplets at a crime scene to reconstruct what happened, climatologists using Glory data will look to the polarization state of scattered light to work backwards and deduce the type of aerosol that must have scattered it.

Nonetheless, interpreting Glory's APS data will be an extremely complex task. The mission will provide such a vast amount of new polarization data about aerosols that, in order to make sense of it, scientists will first have to validate APS science products with ground-based sensors scattered around the globe. Likewise, they will have to adapt and update mathematical techniques developed for an aircraft instrument to ensure they work well in a space environment.

All of this will take some time to refine and perfect. Mishchenko's team expects to release preliminary results as soon as possible after Glory launches, but he also expects to release improved and enhanced versions of Glory's APS data products over time as they are refined.

"Glory has the potential to offer a critical view of aerosols that we have never had from space before," said Glory's Deputy Project Scientist Ellsworth Welton.

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Related Links:

APS Science Home
http://glory.giss.nasa.gov/aps

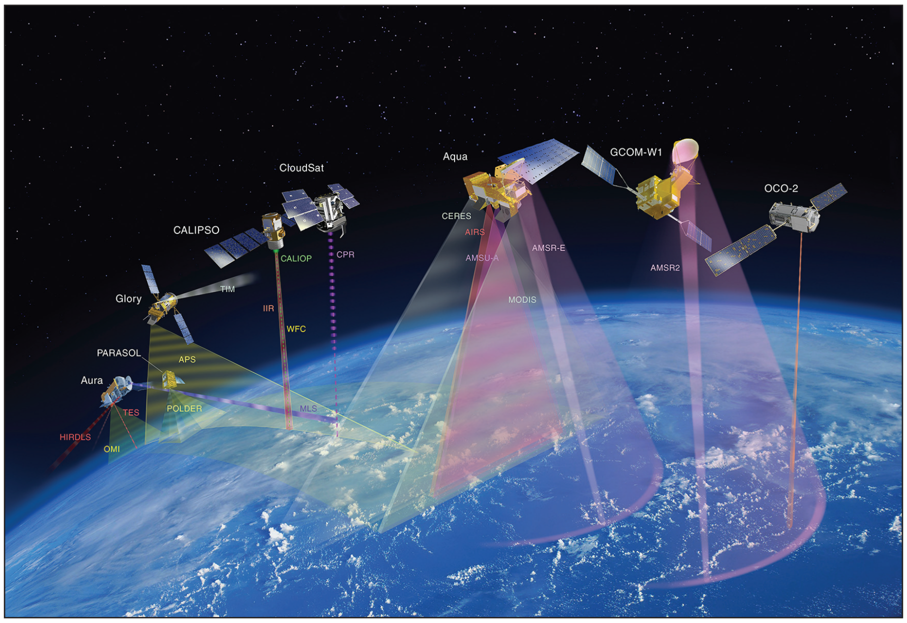
New Aerosol Observing Technique Turns Gray Skies to Blue
http://www.nasa.gov/topics/earth/features/aerosol_clues.html

FEATURE STORIES

WITH A-LIST HELP, GLORY AIMS TO UNRAVEL UNCERTAINTIES ABOUT AEROSOLS

At first glance, the Glory spacecraft might look unassuming.

At 1.9 meters (6.2 feet) by 1.4 meters (4.6 feet), Glory is neither the largest nor the heaviest of NASA's Earth-observing satellites. The whole of the Glory spacecraft is not much taller than most people or wider than an oil barrel. It weighs about 525 kilograms (1,158 pounds), about half the weight of a vintage Volkswagen Beetle. And it has a fairly light load of science instruments—just two.



As depicted here, by about 2014, the international A-Train satellite formation should include OCO-2, GCOM-W1, Aqua, CloudSat, CALIPSO, Glory, and Aura. In December 2009, PARASOL began to leave the formation; it will exit completely by 2012, with Glory taking over its position. Credit: NASA

One of them is an innovative aerosol-sensing instrument called the Aerosol Polarimetry Sensor (APS) that specialists predict will produce dramatic improvements in measuring airborne particles, as well as an important sensor, called the Total Irradiance Monitor (TIM), that will help maintain a three-decades-long record of the sun's irradiance.

Yet, in Glory's case, the value of the mission exceeds that of its parts because in the spacecraft will fly in formation with other Earth-observing satellites. Indeed, when a four-stage, solid fuel rocket—a Taurus XL—launches Glory into orbit in February, the spacecraft will join a series of Earth-observing satellites known as the A-Train.

The "A-Train" likely conjures up visions of jazz legend Billy Strayhorn or perhaps New York City subway trains rather than climate science, but the little-known convoy of satellites has emerged as a critical tool for climatologists.

The four satellites of the A-Train, a group that currently includes Aura, Aqua, CloudSat, Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO), barrel across the equator each day at around 1:30 p.m. local time each afternoon, giving the constellation its name; the "A" stands for "afternoon." It might just as well stand for aerosols, as the A-Train satellites have proven especially important in the study of the tiny airborne particles, which can have an outsized impact on the climate.

"While we have made good progress in observing aerosol effects with current A-Train sensors, Glory should offer even deeper insights into how specific types of aerosols influence the atmosphere both directly and through their impacts on clouds and precipitation," said Tristan L'Ecuyer, a research scientist at Colorado State University and the coauthor of a recent *Physics Today* article about the A-Train. "There is still considerable ambiguity about the dominant types of aerosol in satellite observations and the amount of observed aerosol that can be attributed to human activities," he said.

Depending on their composition and other properties, aerosols can scatter or absorb the sun's heat, and can thus both warm and cool the planet depending on the circumstances. Complicating their climate impact even more, aerosols can also seed clouds and modify clouds. Overall, the particles remain a sort of terra incognita for climate scientists, particularly in comparison to greenhouse gases. "We need to do a much better job of characterizing aerosols in order to improve predictions of, for example, how much temperature will rise over the next 50 years," said NASA Jet Propulsion Laboratory research scientist Jonathan Jiang, also a coauthor of the *Physics Today* story.

Identifying which aerosols are natural and which are human-generated, or anthropogenic, is critical for enhancing climate model accuracy, Jiang explained. However, since there is no reliable way of distinguishing natural from anthropogenic aerosols with satellite instruments in all cases, global estimates of anthropogenic aerosol emissions remain uncertain.

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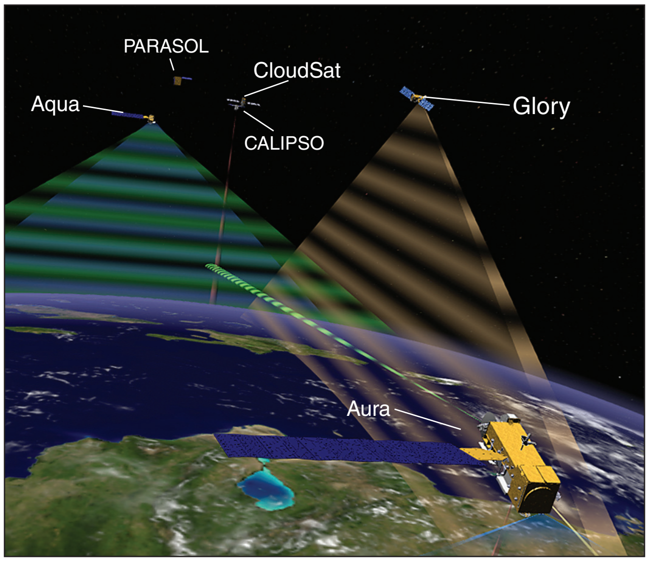

The close proximity of the different spacecraft within the A-Train allows for near-coincident observations between instruments on different spacecraft, providing scientists additional capabilities in their pursuit of answers about the Earth and its climate. Credit: NASA

Black carbon, for example, has both natural and human sources. The sooty particles, which can warm climate by strongly absorbing sunlight and repressing clouds, escape from both tailpipes of diesel engines and the flames of natural wildfires. Parsing out the relative human contribution to black carbon levels is particularly important as recent studies have suggested that the particles may play a key role in Arctic warming, as well as in the retreat of certain Himalayan glaciers.

Glory will help tease out the anthropogenic contribution by offering a more complete accounting of the aerosol types wafting about in a given portion of the atmosphere. When black carbon is found in close proximity to certain types of organic carbon aerosols, for example, wildfires are the likely source. In contrast, if nitrate aerosol or ozone is nearby then combustion engines are more likely.

To make such assessments, climatologists rely on a broad suite of instruments. The current A-Train contains 15 scientific instruments capable of observing the same approximate part of Earth's atmosphere and surface at a broad range of wavelengths.

At the front of the train, Aqua carries instruments that produce measurements of temperature, water vapor, and rainfall. Next in line, CloudSat, a cooperative effort between NASA and the Canadian Space Agency (CSA), and CALIPSO, a joint effort of the French space agency Centre National d'Etudes Spatiales (CNES) and NASA, have high-tech radar and laser instruments that offer three-dimensional views of clouds and aerosols. And the caboose, Aura, has a suite of instruments that produce high-resolution vertical maps of greenhouse gases, among many other atmospheric constituents.

Flight engineers at Orbital Sciences Mission Control Center in Dulles, Virginia will ease Glory into the A-Train behind CALIPSO, a space formerly occupied by the French spacecraft PARASOL. To do this, engineers will rely on hydrazine thrusters, which in Glory's case are slightly larger than expected because they were designed originally for a different mission. (Glory's bus contains some reused parts from a canceled mission, the Vegetation Canopy Lidar.)

Neighboring instruments from A-Train satellites will play a critical role in enhancing Glory's aerosol measurements. One of the most exciting areas of synergy, noted Glory Project Scientist Michael Mishchenko, involves the combination of Glory measurements with those from CALIPSO and CloudSat. CloudSat and CALIPSO can measure the vertical distribution of clouds and aerosols quite well, Mishchenko explained, while Glory's strength lies in characterizing properties of aerosol and cloud particles. "The combination of the microphysics from Glory and the vertical information from CALIPSO will give us a much better view than either instrument could offer alone," Mishchenko said.

Likewise, the Glory team should be able to expand the narrow swath of the Glory APS significantly by combining its data with aerosol measurements from the MODIS instrument aboard Aqua. MODIS can view a much wider swath of Earth's surface than Glory, but has far less ability to discriminate between aerosol types. "We should be able to widen the APS swath from about 6 kilometers to something more like 100 kilometers with the help of MODIS," Mishchenko said, noting that should be enough to meet many needs of climate modelers.

"There's no doubt: Glory is going to play a huge role in the A-Train," he said.

For more information on this topic, contact:

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Related Links:

Introducing the A-Train
http://www.nasa.gov/mission_pages/a-train/a-train.html

Touring the Atmopshere Aboard the A-Train
http://scitation.aip.org/journals/doc/PHTOAD-ft/vol_63/iss_7/36_1.shtml?bypassSSO=1

FEATURE STORIES

THE GLORY MISSION'S JUDITH LEAN DISCUSSES SOLAR VARIABILITY

Though the sun's brightness was once thought to be constant, NASA has launched a series of satellite instruments that have helped show it actually fluctuates in conjunction with cycles of solar activity.

With a new sun-watching instrument called the Total Irradiance Monitor (TIM) scheduled to launch on NASA's Glory satellite in February, we spoke with Judith Lean, a member of the Glory science team and solar physicist at the United States Naval Research Laboratory, about solar cycles and what scientists have learned about solar variability in the last three decades.

What is a solar cycle and how long does it last?
For more than a century, people have noticed that sunspots become more and less frequent on an 11-year cycle. That's the main solar cycle we look at. The 11-year cycle is really part of a 22-year cycle of the sun's magnetic field polarity. The changes are driven by something called the solar dynamo, a process that generates and alters the strength of the magnetic field erupting onto the sun's surface. It's the sun's magnetic field that produces sunspots as it moves up through the sun's surface.

How much does the brightness of the sun change throughout the cycle?
It's a small amount. Total solar irradiance typically increases by about 0.1 percent during periods of high activity. However, certain wavelengths of sunlight—such as ultraviolet—vary more.

What causes irradiance to change?
It's really the balance of sunspots, which are cooler dark areas of the sun, and faculae, bright areas that appear near sunspots. The faculae overwhelm the sunspots, so the sun is actually brighter when there are more sunspots.

Can changes in the sun affect our climate?
If it weren't for the sun, we wouldn't have a climate. The sun provides the energy to drive our climate, and even small changes in the sun's output can have a direct impact on Earth. There are two ways irradiance changes can alter climate: One is the direct effect from altering the amount of radiation reaching Earth. The second is that solar variability can affect ozone production, which can in turn affect the climate.

Does the 0.1 percent change in irradiance affect Earth's climate much?
Solar irradiance changes are likely connected to dynamic aspects of climate—things like the coupling of the atmosphere and ocean—El Niño being one example—or aspects of atmospheric circulation, such as the Hadley cells that dominate in the tropics.

Photo courtesy Judith Lean

But we've done a great deal of modeling, and the sun doesn't explain the global warming that's occurred over the last century. We think changes in irradiance account for about 10 percent of global warming at most. Of course, there are also longer cycles that may have an impact on climate, but our understanding of them is limited.

There is disagreement about whether the last three cycles have gotten successively brighter. Has that been resolved?
No, it hasn't. The best understanding is that irradiance cycles have been about the same in the last three cycles, but one group reports an increasing trend whereas another group says that current levels are now the lowest of the entire 30-year record. I believe these differences are due to instrumental effects, but we really need continual, highly accurate, and stable long-term measurements to resolve this. The radiometer aboard Glory—the Total Irradiance Monitor (TIM)—will be a big step, quite an exciting advance.

What part of the 11-year cycle will Glory observe?
Glory is going to observe during the ascending phase of the cycle. The ascending phase is relatively rapid, so we should get to the peak in about three years. Then there will be about two years or more when solar activity is high and stays high. About five years from now, activity will start to come down again so that by, say, 2019 we will be at low levels again.

What do you hope Glory will find?
The Glory TIM has been calibrated more rigorously than

GloryScienceWritersGuide.indd 12 1/10/11 5:05 PM

previous instruments, so it should help a lot in getting the absolute brightness of the sun. In addition to recording the ever-changing irradiance levels, it should measure irradiance precisely enough that will make it feasible to determine whether solar irradiance is stable or changing, if the measurements continue long enough into the future.

Are there aspects of the solar variability that TIM won't measure?
Yes. The Glory TIM looks at overall irradiance, but it doesn't measure how specific parts of the spectrum—the ultraviolet, visible, or infrared—are changing. Some of the largest changes actually happen at the shortest wavelengths, so it's extremely important that we look at the spectrum. There's an instrument related to TIM called the Solar Irradiance Monitor (SIM) aboard the SORCE satellite that lets us see how individual parts of the spectrum vary, and it's also critical.

The sun has been exceptionally quiet in recent years. Are we entering a prolonged solar minimum?
There was a period from mid-2008 to mid-2009 when the sun was without sunspots for many days. It was probably the quietest period we've seen since the first total solar irradiance measurements. But we didn't go into a prolonged minimum because the sun still had a few active regions—not sunspots, but small bright faculae regions—and we could see the irradiance continue to fluctuate throughout this very quiet period. Now there are more dark sunspots and more bright faculae on the sun's surface, so activity is ramping up and a new cycle—solar cycle 24—has started.

For more information on this topic, contact:

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Related Links:

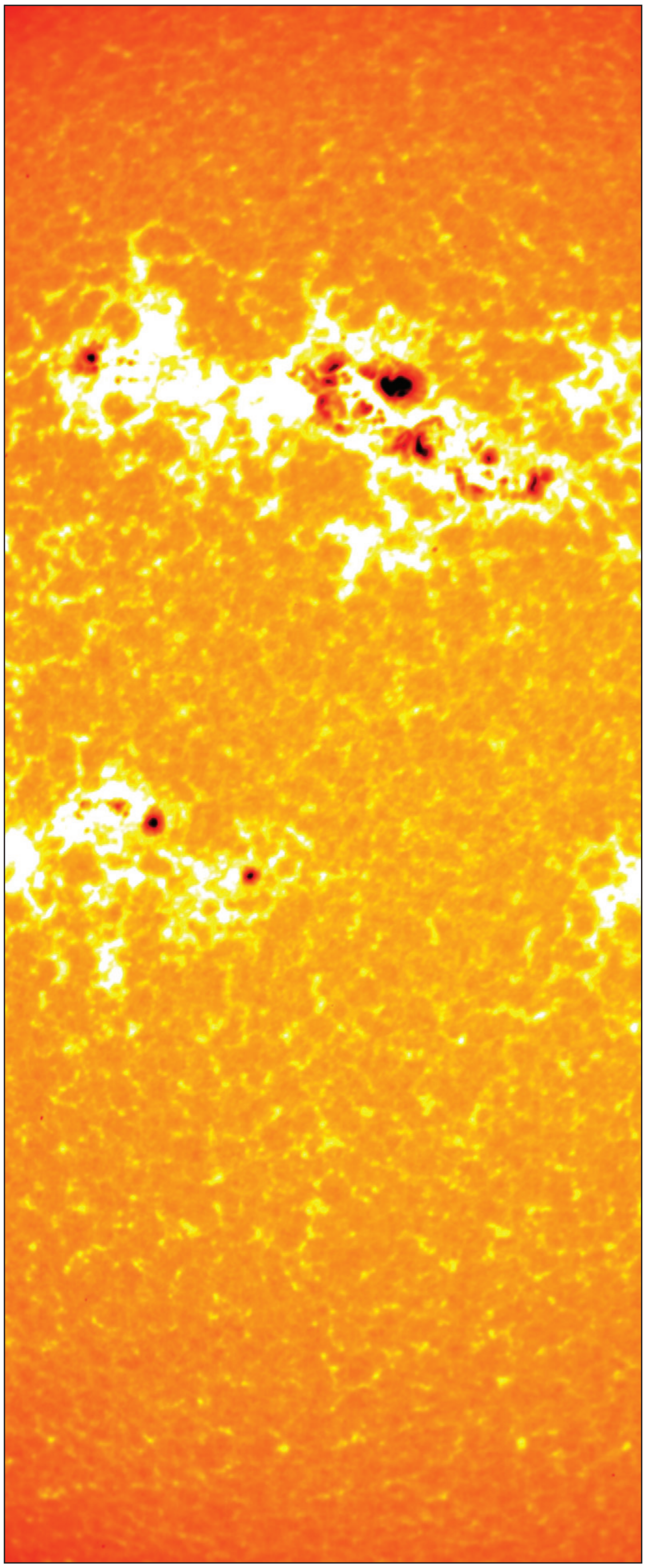
Changing Sun, Changing Climate
http://www.aip.org/history/climate/solar.htm

New Sun Watching Instrument to Monitor Sunlight Fluctuations
http://www.nasa.gov/topics/earth/features/glory_irradiance.html

TIM Website
http://lasp.colorado.edu/sorce/instruments/tim.htm

GISS Total Irradiance Monitor Page
http://glory.giss.nasa.gov/tim/

SORCE Website
http://lasp.colorado.edu/sorce/index.htm



Although sunspots cause a decrease in irradiance, they're accompanied by bright white blotches called faculae that cause an overall increase in solar irradiance. Credit: NASA/SORCE

GloryScienceWritersGuide.indd 13 1/10/11 5:05 PM

GLORY SPOKESPERSONS

Michael Mishchenko is a senior scientist at the NASA Goddard Institute for Space Studies in New York City and the project scientist for the Glory satellite mission. His research interests include electromagnetic scattering, radiative transfer, and remote sensing. Mishchenko was a project manager for the NASA/WCRP Global Aerosol Climatology Project (1998–2002) and has been the Glory Project Scientist since 2003. He is a recipient of the N. P. Barabashov Award of the NASU, the Henry G. Houghton Award of the American Meteorological Society, the Arthur S. Flemming Award of the George Washington University, the NASA Exceptional Scientific Achievement Medal, and many other professional awards.

Brian Cairns has been a scientist NASA's Goddard Institute for Space Studies (GISS) in New York City since 2007. In this role, he has worked on the development of the Aerosol Polarimetry Sensor (APS) and the Cloud Cameras for the Glory mission and serves as instrument scientist for these instruments. He is also the developer of the data processing system for the APS and cloud camera data at GISS that will derive the geophysical products from the APS and cloud camera data. He and his colleagues at GISS perform research on advanced numerical techniques for retrieving information from multi-spectral and multi-angle data that are being used in this data processing system.

Greg Kopp, the TIM Instrument Scientist for the Glory mission, is an experimental solar physicist and instrumentation scientist. He is a specialist in radiometry, interferometry, electro-optics, and infrared systems, as well as satellite, airborne, and ground-based facility instrumentation. Kopp has worked at the Laboratory for Atmospheric and Space Studies at the University of Colorado, Boulder for nine years. His mission experience includes: Hyperspectral Imager Instrument Incubator Program Principal Investigator, TSI Radiometer Facility Principal Investigator, SORCE Co-Investigator and TIM Instrument Scientist, and NPOESS/TSIS/TIM Instrument Scientist.

Bryan Fafaul has worked at the Goddard Space Flight Center for more than 22 years in a wide variety of technical and management positions. Bryan started his career in Electrical, Electronic, and Electromechanical (EEE) Parts Branch and then moved into project management. Prior to his current mission, he has served as the Mission Manager for the Wide-Field Infrared Explorer (WIRE), the Hubble Space Telescope (HST) Instrument Systems Manager for Servicing Mission 3A, 3B and 4, and the Deputy Project Manager for the NPOESS Preparatory Project (NPP).

Joy Bretthauer is the Glory mission's Program Executive in the Earth Science Division of NASA Headquarters' Science Mission Directorate. Since 1985, she has served NASA in various engineering and management roles. Prior to becoming the Glory Program Executive, she provided both management and systems engineering expertise for the first three flight avionics systems on the Express Logistics Carrier(s), managed by Goddard Space Flight Center's Express Logistics Carrier Project, for the International Space Station. For eight years, she served as the Observatory Manager for the Fermi Observatory, a Gamma-ray Telescope for Astrophysics, launched in June 2008. She has provided engineering support for other Earth Science missions, including LandSat 7 and Earth-Obiter 1 (EO-1). Bretthauer has an electrical engineering degree from Carnegie Mellon.

Credit: NASA

GloryScienceWritersGuide.indd 14 1/10/11 5:05 PM

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NASA/GISS	NASA Goddard Institute for Space Studies	SIGMA	Sigma Space Corporation
NASA/GSFC	NASA Goddard Space Flight Center	STSI	Stellar Solutions, Inc.

GloryScienceWritersGuide.indd 15 1/10/11 5:05 PM

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